Chernobyl accident

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The Chernobyl Accident

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THE CHERNOBYL ACCIDENT

ISSUE DEFINITION

On 26 April 1986, the town of Chernobyl, located 60 miles north of the Ukrainian capital of Kiev, became the site of the most serious accident ever known to have taken place in a nuclear power reactor. A series of human errors, combined with what some western experts believe to be serious design flaws, resulted in a catastrophic explosion and fire involving the core of the reactor itself. The immediate results of the explosion and fire were the death of two people on the site and a very large release of radioactivity. The unprecedented release of dangerous fission products from the reactor core necessitated the evacuation of tens of thousands of people, and contaminated an area of approximately 300 square kilometres of rich farmland. The radiation spread across international boundaries, contaminating food and causing much concern over long term health and environmental effects.

This review will provide details of the Soviet nuclear power program, the accident at Chernobyl and the cleanup efforts which have been made to date. In addition, the short and long term health effects of the accident will be discussed, as will its social and economic impacts. Finally, a brief comparison will be made of the Soviet RBMK reactor involved in the Chernobyl disaster and the CANDU reactor.

BACKGROUND AND ANALYSIS

A. The Soviet Nuclear Power Program

Even though the Soviet Union has large reserves of mineral fuels, it has implemented an ambitious nuclear energy program. This was

done largely because, while 80% of its mineral fuel resources are found in eastern regions of the country, some 75% of the consumers of power are concentrated in the European (western) part of the USSR. In 1985, the USSR had 51 nuclear power units, with a capacity of 26,099 MWe (megawatts of electricity). These reactors accounted for about 11% of Soviet electrical production. A further 35 units, with a capacity of 34,725 MWe, were under construction in 1985 and the rate of introduction of nuclear power plants was increasing rapidly. In fact, nuclear power plants were being built at a rate two and one-half times the rate of construction of other types of power plants using organic fuels. In the European region, as of this year, virtually all new power plants are nuclear. The USSR's most recent five-year plan (1986-1990), proposes an additional 38 units and calls for nuclear energy to supply 20% of all Soviet electricity needs by 1990.

The Soviet nuclear program uses three types of thermal power reactors: the PWR (WWER in Russian terminology) or pressurized, light-water-moderated and cooled reactor; the LWGR (RBMK in Russian terminology) or the light-water-cooled, graphite-moderated reactor; and the sodium-cooled fast breeder reactor. Of the 51 reactors in operation in 1985, four were fast breeder reactors, 19 were WWERs and 28 were RBMKs.

The four reactors at Chernobyl are of the RBMK type. Like Canada's CANDU system, the RBMK encloses the fuel bundles in individual channels to permit refuelling of the reactor while it is in operation. Graphite is used as a moderator rather than heavy water as in the CANDU system.

There are many other graphite-moderated reactors in use around the world - but most are cooled with helium, air or other gases. Outside the Soviet Union, the only other <u>water-cooled</u>, graphite-moderated reactor in use today is that operated by the U.S. Department of Energy at Hanford, Washington. This reactor, like the RBMK in the USSR, was initially designed to produce plutonium for weapons, but was later modified to supply steam for electricity generation. Also of interest is the fact that, like the RBMK reactor at Chernobyl, the Hanford reactor has no containment structure.

Until the accident at Chernobyl, the RBMK-type reactors were producing over 64% of all nuclear-generated electricity in the USSR. Plans are also underway to introduce a new 1,500 MWe RBMK series by altering the fuel elements to intensify heat transfer within the existing fuel channels.

An RBMK reactor at Ignalina, Lithuania has been operating in this new mode for three years now and in December 1986 a second one also became operational. These two reactors are causing concern in Sweden because of their proximity to that country. A study by the Swedish State Power Board claims that safety margins at these facilities are even narrower than they were at Chernobyl. The alterations made to the reactor make it more difficult to ensure continuous cooling of the core. In the event of an uncontrolled rise in core temperature, seals around the fuel elements could melt, causing massive radioactive leaks. The Soviet Union, on the other hand, contends that additional safety measures, including extra neutron absorbers and a faster acting shut-down system will ensure the safety of the Ignalina reactors.

It is important to note that, unlike most reactors in the Western World (including the CANDU), there is no containment structure around any of the RBMK reactors. These structures were probably eliminated for economic reasons, although the Soviets claimed that the inherent safety of the reactor system made them unnecessary. Events at Chernobyl would seem to point out the wisdom of including this important safety feature. Without the presence of a containment structure, the 1979 accident at Three Mile Island in the United States would have had far more serious consequences than it did.

Since the accident at Chernobyl, a number of press reports have dealt with details of the Soviet nuclear program - in particular the warnings about certain features of its reactors which have been issued by Soviet and foreign scientists and engineers over the years. For example, Lord Marshall, Chairman of Britain's Central Electricity Generating Board, noted that after a visit to the Soviet Union in 1975, he had listed a series of flaws in the Soviet RBMK reactors, pointing out that their huge physical size made fluctuations in the chain reaction difficult to control. Soviet nuclear engineers had been told at that time that these

reactors were so flawed and unsafe that they could never be built in the West.

Within the Soviet Union, there has been criticism as well, but this related less to design problems than to problems of material quality. The Soviet Union uses a standardized reactor design for its 1,000 megawatt reactors. To economize on production costs, a centralized nuclear power plant "factory" was set up at Volgodonsk. The purpose of this "Atommash" plant was to manufacture all the parts for 1,000 megawatt light-water reactors. The plant was supposed to supply eight complete reactors each year but from the start of construction in 1976 it has been plagued by problems. In July 1983 Pravda printed a long list of serious construction and operation difficulties at the plant. The same article implied that the nuclear components produced at the plant were not of acceptable quality.

With specific reference to the Chernobyl reactor, an article in a Kiev newspaper quoted a highly placed worker at the reactor site as being critical of acute materials shortcomings, shoddy workmanship and low morale.

B. The Accident at Chernobyl

On 25 August 1986 the Soviet Union presented a detailed report on the causes of the Chernobyl disaster at a special meeting of the International Atomic Energy Agency (IAEA) in Vienna. Ironically, the most serious nuclear reactor accident of all time occurred in the course of a safety test. Apparently workers were trying to determine how long the turbine generators would continue to turn due to inertia in the event of an unplanned reactor shutdown. To carry out this experiment, the workers committed no less than six serious errors - including shutting off all the reactor's automatic safety systems so that they would not interfere with the experiment.

The chain of events started on April 25 when the power level in the reactor was reduced. Because automatic control systems were in place to prevent the reactor's operation at such low levels, the workers

shut them off. This removed one of the safety systems designed to prevent the reactor from going out of control. Power levels then dropped too low for the test, and in trying to bring the reactor back up to the required level, technicians committed the second fatal error. Control rods are used to regulate and, as the name implies, control the chain reaction in the reactor. In the RBMK there must be a minimum of 30 control rods inserted in the reactor at all times. Technicians at Chernobyl removed all but six to eight of the rods. To compound the problem, a second safety system, which would have automatically shut down the reactor when the turbines stopped, was also disconnected for the test.

The actual test started at 1:23 a.m. on April 26 when power to the turbine was stopped. Just before this was done, the flow of water to cool the reactor was reduced and safety devices that would shut down the reactor in the event of abnormal steam pressure or water levels were disengaged. This latest manoeuvre caused the reactor to start overheating dangerously, but, because the emergency cooling system had been shut down 12 hours before, there was no relief from the heat buildup. Within seconds, a tremendous power surge caused two explosions which blew the roof off the reactor building and ignited over 30 fires around the plant. The damaged reactor core and the surrounding graphite moderator started burning at temperatures up to 1600°C. The fire burned for 12 days, releasing massive amounts of radiation into the atmosphere.

Exactly how much radioactivity was released into the atmosphere is not yet known, but numerous estimates have been made. One U.S. estimate holds that at least 40 million curies of radioactivity were released; this compares well with the Soviet estimate of 50 million curies noted in their report to the IAEA. This represents about 3.5% of the radioactivity of the core. (By comparison the Three Mile Island accident in the United States released only 15 curies of Iodine-131.) While it is hard to compare this release with that of Hiroshima or Nagasaki, because the fission products involved are different, one radiation physics expert says that, roughly speaking, the Chernobyl accident released an equivalent of 30 to 40 times the radiation of those atomic bombs.

Much of the radiation fell on the plant site and surrounding towns and farms, but some was carried into several neighbouring countries, including Sweden, Poland, Romania, Switzerland, West Germany and Yugoslavia. In these countries, radiation levels temporarily increased severalfold over normal levels. In the town of Chernobyl, 12 miles from the site of the accident, a maximum radiation of 15 millirems/hour was reported. Normal background radiation in most parts of the world is about 0.01 millirems/hour.

C. The Cleanup

The reactor site fires which did not involve the graphite core were extinguished within hours of the explosion. The extremely hot fire in the graphite core was, however, another matter. No such large graphite fire had been fought before and so there was little or no domestic or international experience on which to draw. Water could not be used for fear its rapid dissociation in the extreme heat would produce more hydrogen and trigger further explosion. On the other hand, it might simply have vapourized and formed radioactive steam, spreading still more radioactivity. Instead, a series of materials - each designed to deal with some particular aspect of the fire - was used. Layers of boron carbide were dumped by helicopter onto the fire to reduce the chances of a renewed chain reaction. In addition, dolomite was dumped on the fire to act as a heat sink and as a source of carbon dioxide to smother the fire. Metallic lead was used to stop radioactive emissions and layers of sand and clay were added in the hope that they would absorb radioactive particles. This latter addition was later found to have been counter-productive as the thermal insulation provided by the sand and clay may have contributed to a rise in the core temperature a week after the accident. This in turn led to an unexpected increase in the release of radioactivity. Nonetheless, by 9 May the graphite fire had been extinguished with the help of some 5,000 tons of sand, clay, boron and dolomite, along with large quantities of cold nitrogen gas that were pumped into the core to smother it and blanket it from incoming air.

Work now started on construction of a massive reinforced concrete slab with an embedded cooling system (heat exchanger) underneath the damaged reactor. Despite some problems with the supply of concrete, the slab was reported to have been completed ahead of schedule at the end of June. This slab is intended to act as a barrier to groundwater contamination. **By November the entire damaged reactor structure was entombed in 300,000 tonnes of concrete. The fear that this would result in a build-up of heat within the structure has been shown to be unfounded as the cooling system built into the concrete base has in fact not been required.**

In another project at the site, dikes were constructed to block the flow of any contaminated streams of rainwater from reaching the Pripyat River. Until these dikes were completed, Soviet officials were taking no chances, and to prevent rainfall on the reactor site, threatening clouds were being dispersed with chemicals dropped from large aircraft. One further precaution has been taken; a new water supply for the city of Kiev was established. **However, continuous checks of the regular water source through to mid-1987 showed no increase in radioactive contamination.**

Steps have been taken continuously since May 1986 to remove contaminated soil and to return the whole reactor complex site to radioactivity levels comparable to those prior to the accident.

D. The Impact

1. Health Effects

The immediate health effects of the Chernobyl accident are not difficult to assess. So far 31 people have died as a result of the explosion and subsequent release of radioactivity. **All the 300 or so other people who were treated for acute radiation sickness have been released from hospital. No further deaths have been reported.** As for the long-term health effects of Chernobyl, the picture becomes much more clouded and there is debate over how many people will be affected.

The main long-term health concern is radiation-induced cancer and, as one expert points out, the long-term health hazards of the tragedy are the greatest unknown. The questions which must be answered in making any reasonable estimate are how much radiation was received by how many people for how long. In short, then, it is the dose of radiation that is the important factor. Radiation dose is measured in units called rems. One rem (for roentgen-equivalent-man) produces the same biological effect as one roentgen of x-rays. The natural background level of radiation varies with altitude and local geology - but is between 26 and 170 mrem (millirems) per year. The damage done by radiation depends on the dose. For example, an exposure to 5,000 rems kills almost immediately, and a dose above 1,000 rems causes death within days. Levels near Chernobyl may well have approached that, since Soviet authorities were still reporting levels of 200 rems/hour in mid-May. Thus a life-threatening dose could be absorbed in just five hours.

A whole-body dose of 400 rems over several days kills half its victims within a month, while the other victims recover. A dose of 150 rems over a week is survivable but many victims will experience the symptoms of radiation sickness, first of which are loss of appetite, nausea and vomiting. These symptoms can disappear the second week after exposure only to be followed by weight loss and lethargy as the gastrointestinal tract becomes unable to digest nutrients. Damage to bone marrow drastically reduces white blood-cell counts and destroys the body's immune system.

The effects of radiation also vary according to the isotope involved. For example, radioactive barium resembles calcium in its atomic structure and so concentrates in the bones. Caesium, which resembles potassium, concentrates in the muscle, while radioactive iodine concentrates in the thyroid.

In trying to assess how many cancers will result from the Chernobyl accident, experts are using the following sort of model:

> ... for every million people exposed to one rad (a unit of measurement similar to the rem) beyond background radiation, there will be one or two cases of leukemia added to the "natural" annual level of 60 cases per million people. Leukemias will start showing up in 2 years and peak in 10 to 15 years. Similarly, each extra rad that 1 million people are exposed to will trigger 5 extra cases of thyroid cancer within 10 years, compared with a normal 40; 7 extra cases of lung cancer, compared with 700; 6 to 10 additional cases of breast cancer compared to 750 expected otherwise.(1)

This estimate is not the only one in use, of course, and there is often wide disagreement among scientists - especially about the effects of very low levels of radiation. Nonetheless, this is an example of a process by which estimates of Chernobyl's long term effects are being calculated. Once the Soviet Union released its report to the IAEA on the technical details of the Chernobyl disaster (including how much radiation was released) it was possible to plug the numbers into the above type of model and come up with some estimates. The most widely reported estimates vary from 2,000 to 6,500. That is to say that experts expect anywhere from 2,000 to 6,500 extra cancer deaths over the next 50 to 70 years as a result of Chernobyl. Other experts expressed the fear that this number could be much higher due to the possible contamination of the food chain by caesium 137 and caesium 134. Caesium lodges in tissue and in muscle and delivers a large dose of radiation to those who absorb it. However, by September 1986 examinations of 1000 members of the exposed population had revealed that 97% of these people had ten times less caesium in their bodies than expected. **Continued monitoring has also shown no enhanced levels of retardation in babies born in the region, a problem that had been predicted by several experts.** Such results leave room for optimism that the long-term effects may be much lower than expected.

Radiation levels decrease rapidly with distance from the site and so the 200 million people in Eastern and Central Europe who were briefly exposed to the radioactive cloud from Chernobyl received relatively small extra doses of radiation - about the same as those received by a

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(1) S. Begley, "The 20th-Century Plague", Newsweek, 12 May 1986, p. 36-37.

generation exposed to the peak of global fallout from atmospheric testing of nuclear weapons during the early 1960s. If, before the accident, the lifetime risk of cancer was, for example, 20%, it may now be 20.005%.

2.- Social and Economic Impacts

The social and economic effects of the Chernobyl disaster will be as far reaching and devastating as the health effects.

First there is the matter of dealing with the 135,000 evacuees who left their homes on two hours' notice, taking nothing but a suitcase with them. **Houses, food, clothing, schools - in fact, whole villages - have been built or made available. By the end of 1986, 24 settlements in the Chernobyl district had been decontaminated and were being reoccupied. The cost of the upheaval in human terms will be great. While children have been found to have adapted remarkably well to the trauma of moving, a lot of the evacuees yearn to return "home".** Some people evacuated from their homes in southern Byelorussia were resettled in new villages in the northern part of the region - partly because of a shortage of workers there but also because officials did not want to risk letting them return to their homes just north of the reactor site.

In economic terms, the accident has also been a disaster for the Soviet Union. In addition to the cost of resettling 135,000 people, it faces the loss of the $1.9 billion plant itself, a cleanup bill in the hundreds of millions of dollars and the loss of 10% of its nuclear generating capacity - which is being replaced with more expensive electricity from coalfired generating stations. This potential loss of electrical production is so serious that in October 1986 Units 1 and 2 were restarted and Unit 3 at Chernobyl, which shares a control room and generating equipment with the unit destroyed in the accident, will be restarted in the latter part of 1987. Western experts are very concerned about this move, but the shortage of electricity is reportedly so severe that the Soviets feel they have no choice. On top of these costs comes the cost of changes to all RBMK reactors in the country to improve safety standards. Control rods will be fitted with new stops preventing the last 1.2m from being pulled out of the reactor; fuel enrichment will increase from 2.0 to 2.4%;

some systems will be added for flooding reactors with neutron absorbing liquids or gases for rapid emergency shut-down; and finally, more instrumentation will be installed to allow closer scrutiny of the state of the reactor. Most of these improvements have been installed while the rest are to be in place by the end of 1987.

The Soviet Union also faces the loss of agricultural produce and, potentially, of much valuable farmland. One American study puts the total cost of the accident to the Soviet economy at $3.7 to $6 billion (U.S.). The Soviets themselves admit to direct losses of some $3.6 billion (U.S.).

Beyond the borders of the Soviet Union the accident has meant a loss of some $35 million in agricultural exports and $5 million in tourism for Poland. Hungary reports a cost to its economy of some $50 million and several other East European countries report losses in the tens of millions of dollars.

Of the Western European nations in the path of Chernobyl's radioactive cloud, Sweden has suffered the greatest loss - especially in Swedish Lapland. In this area, the reindeer have shown such increased levels of caesium that a five-year ban has been imposed on the slaughter of reindeer for meat. Deprived of their livelihood and food source, Lapps are also being faced with the destruction of their culture. Mass graves were dug for the carcasses of up to 40,000 reindeer slaughtered last fall, some of them containing up to 15,000 becquerels of caesium per kilogram. The acceptable limit in Sweden is 300. It is estimated that the Chernobyl accident has so far cost Sweden $40 million, and the final cost could reach $200-$300 million. West Germany's bill is said to be $100 million and rising, while still another estimate puts the loss to all Western European countries at a half-billion dollars.

E. The CANDU Comparison

Since the accident at Chernobyl, a number of comparisons between the RBMK reactor and the CANDU reactor have appeared in print. Nuclear detractors are quick to point out the similarities, while

supporters of nuclear power have been just as quick to point out the differences. Both arguments are presented here. Any definitive statement on the relative safety of the CANDU revealed by events at Chernobyl will have to await the completion of more detailed analyses currently underway.

It has been noted that the CANDU is the closest commercial cousin to the RBMK reactor. The key common design feature is the pressure tube. Most commercial power reactors use a single, thick, stainless steel "pressure vessel" to contain the entire core. CANDUs and RBMKs, on the other hand, contain the nuclear reaction within hundreds of "pressure tubes". In both reactors the pressure tubes and fuel sheaths are made of the exotic metal zirconium. These reactors contain five to six times the zirconium of U.S.-style light-water reactors.

Zirconium is a safety concern because of its potential for producing hydrogen under great heat. In the 1979 accident at Three Mile Island it was a hydrogen/steam reaction which resulted in the explosion that damaged the unit. The subsequent build-up of a hydrogen bubble was the greatest concern during the days that followed the initial explosion; a large hydrogen explosion could have destroyed even more of the reactor and possibly breached the containment structure.

A second common feature of the two reactors is the "positive void coefficient". This is a technical term meaning that, if a serious loss of coolant occurred, reactor power, heat and radiation levels would surge upwards - even if the chain reaction in the core was shut down within seconds. Most other commercial nuclear power reactors automatically begin to lose power when coolant is lost. In the CANDU, however, there is an excellent on-line computer control system which constantly monitors conditions in the core. In the RBMK, the instrumentation is far less sophisticated.

Another similarity which has been pointed out is the on-line refuelling ability of CANDU and RBMK reactors. These reactors can be refuelled with uranium without being shut down completely, unlike other reactors around the world. It has also been noted that at Chernobyl the initial explosion brought down the heavy on-line refuelling gantry on top of the reactor, damaging the pipes of the emergency core-cooling system.

This would not be the case if a similar event occurred in a CANDU reactor because that reactor's pressure vessels are in a horizontal configuration, rather than a vertical one, as in the RBMK; fuelling is done from the front, not the top of the reactor.

Supporters of the CANDU point out that while there are certain similarities between the two types of reactors there are also some crucial differences, the most significant being the absence of graphite in the CANDU reactor. In the CANDU heavy water moderates the chain reaction and, unlike graphite, heavy water is not flammable. At Chernobyl it was the graphite fire which continued to emit highly radioactive fission products into the atmosphere from the core of the reactor for nearly three weeks after the initial explosion. In the CANDU, even if no coolant was available to the fuel (in itself a highly unlikely, though not impossible, event) the moderator would help to remove the excess heat and prevent a core melt. In addition the water in the containment structure would dissolve certain radioactive compounds such as caesium iodide, preventing it from escaping into the air. Both the heavy water moderator and the containment structure are missing in the RBMK design.

This absence of the massive concrete containment structure in the RBMK is another of the crucial differences between the two types of reactor, although detractors of nuclear power argue that massive hydrogen explosions could still breach the containment. In addition to this concrete structure, Ontario Hydro's multi-unit CANDU stations also have a unique vacuum-containment system designed to suck up radioactive gases accidentally released and store them until they become harmless.

Finally, if a CANDU reactor suffered severe core damage, the chain reaction in the fuel would not restart, as it could in the RBMK, because CANDU is fuelled by natural uranium, rather than the slightly enriched uranium that the Soviets use.

The bottom line for nuclear critics is that if all the safety systems in the CANDU failed or were taken out of service by operators, a catastrophic explosion and release of massive amounts of

radioactivity could occur. In the USSR, the presence of relatively few private cars, which would impede evacuation by clogging roads, and the presence of a central planning authority were responsible for allowing the evacuation of over 130,000 people fairly quickly. What would happen in and around Toronto if there was a major accident at Pickering?

The supporters of nuclear power say that the CANDU system presents a defence in depth, with a large number of redundant safety systems and a well trained operational staff. They feel that it is inconceivable that any operators at CANDU stations would act as those at Chernobyl did and simultaneously shut down all safety and emergency response systems.

CHRONOLOGY

26 April 1986 - An explosion occurred in Unit 4 of the Chernobyl Nuclear Plant in the USSR. The explosion damaged the reactor and started fires in the plant. The graphite core of the reactor began to burn.

27 April 1986 - The first 25,000 people were evacuated from an area within a 10 km radius of the stricken plant.

28 April 1986 - The governments of Sweden, Finland and Denmark reported abnormally high levels of radioactivity in the atmosphere and demanded an explanation from the Soviet Union.

29 April 1986 - The Soviet Union officially acknowledged that an accident had occurred at the Chernobyl site and that two people were dead and 197 others hospitalized.

2-4 May 1986 - A further 100,000 people living within 38 km of Chernobyl were evacuated.

5 May 1986 - Radiation levels within the 38 km zone were found to have dropped from 10-15 millirem/hr. to 2-3 millirem/hr. Normal background radiation would be about 0.01 millirem/hr.

9 May 1986 - The graphite fire in the reactor's core was finally extinguished.

15 May 1986 - Schools in Kiev closed several weeks early and children were sent away to summer camp.

3 June 1986 - A revised death toll for the accident indicates 23 people had died from radiation, in addition to the two who died in the initial explosion. A further 299 people were suffering from acute radiation sickness and 30 of these were in critical condition.

25 August 1986 - The Soviet Union presented its technical review of the Chernobyl accident at an IAEA conference in Vienna. The cause of the accident was said to have been a series of gross breaches of regulations; lack of control by official agencies; irresponsibility, negligence and indiscipline.

29 August 1986 - The IAEA conference concluded with the presentation of a 13-point list of proposals for the improvement of nuclear safety. An International Safety Advisory Group will study the information presented at the conference and report to the IAEA.

October 1986 - Units 1 and 2 at Chernobyl were restarted.

November 1986 - Construction of the concrete sarcophagus to entomb Unit 4 was completed.

June 1987 - Construction of Units 5 and 6 at the Chernobyl site was cancelled.

July 1987 - Six senior officials at the Chernobyl complex were tried and sentenced for violating safety rules and for negligence. Three, including the plant director, were given 10 years' hard labour, while the others received sentences of two to five years.

late-1987 - Soviet officials hope to restart Chernobyl Unit 3, which is just 150 metres from the damaged reactor and shares its control room.

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